Solar Polar Jets Driven by Magnetic Reconnection with Gravity and Wind

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A Polar Sea of Coronal X-ray Jets

Hinode XRT, 2007 January 10; Cirtain et al. 2007, Science, 318, 1580

A Polar Vortex Jet into the Heliosphere

STEREO EUVI/COR, 2007 June 7; Patsourakos et al. 2008, ApJ, 680, L73

Magnetic Geometry

Polar jets originate from islands of minority polarity embedded in a sea of majority-polarity open field

The magnetic structure has dome-shaped fan surface separating closed field inside from open field outside

A null point atop the dome is susceptible to stresses that form current sheets there (Antiochos 1995)

Reconnection across the sheet enables exchange of mass, flux, and energy between closed & open field

Antiochos 1995, in ASP Conf. Ser. 95, 1

Surface Dynamics

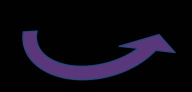
Surface convection shuffles, compresses, rarefies, stretches, twists, and intertwines elemental flux tubes

Disturbances in open-field regions can propagate away into the solar wind

Disturbances in closed-field regions are confined and cannot escape, building up magnetic twist and energy

Eventually, some mechanism – likely reconnection-moderated – initiates explosive energy release that powers the jet

Embedded Bipole Model



A dome-shaped fan surface separates closed (*black*) from open (*white*) magnetic field lines with a null point in a high-beta region (*red lozenge*); twisting flows (*magenta arrow*) energize the field.

Simulated Reconnection-Driven Jets

In previous work (Pariat et al. 2009, 2010), basic predictions of this model for jets were verified for

- Cartesian geometry
- No gravity
- No solar wind

In this effort, we seek more realism by including

- Spherical geometry
- Solar gravity
- Solar wind

Pariat et al. 2009, ApJ, 691, 61; 2010, ApJ, 714, 1762

Numerical Simulations – *ARMS*

*A*daptively *R*efined *M*agnetohydrodynamics *S*olver
- e.g. DeVore & Antiochos (2008); Pariat et al. (2009, 2010); Karpen et al. (2012); etc.

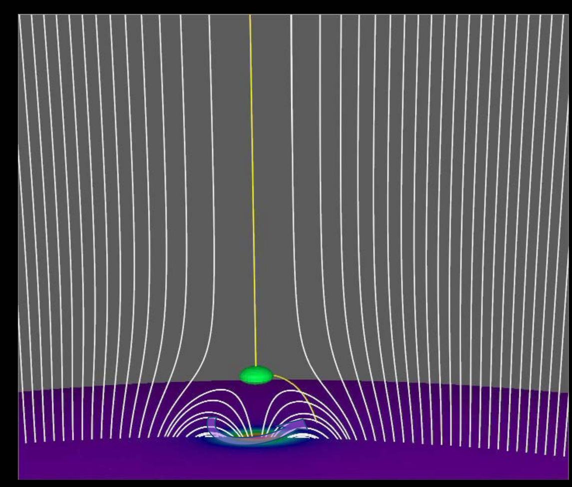
High-fidelity shock-capturing MHD algorithms
- DeVore (1991)

Adaptive mesh refinement toolkit *PARAMESH*
- MacNeice et al. (2000)

Massively parallel computations – NASA HEC, DoD HPC

Essential MHD physics
- Flux conservation, spherical geometry, gravity, solar wind

Initial State



$t = 0$ s

Uniform field = –2.5 G

Max bipole field = +35 G

Temperature = 1 MK

Base density = 10^8 cm^{-3}

Dome radius = 20 Mm

Null height = 15 Mm

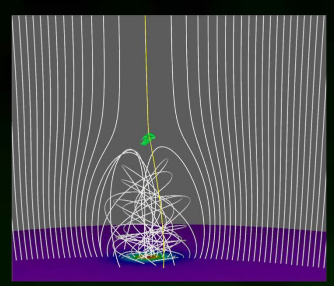
Isothermal solar wind

Subsonic twisting flows @ 20 km s^{-1} energize the field within the bipole

Slow Energy Build-up Phase

$t = 625$ s

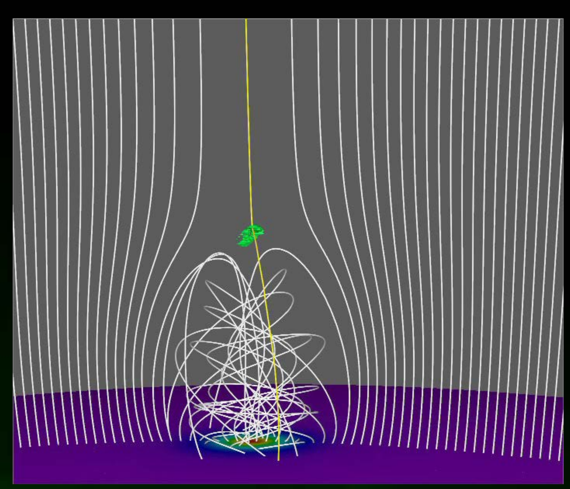
$t = 1250$ s



$t = 1875$ s

$t = 2500$ s

Onset of Symmetry Breaking



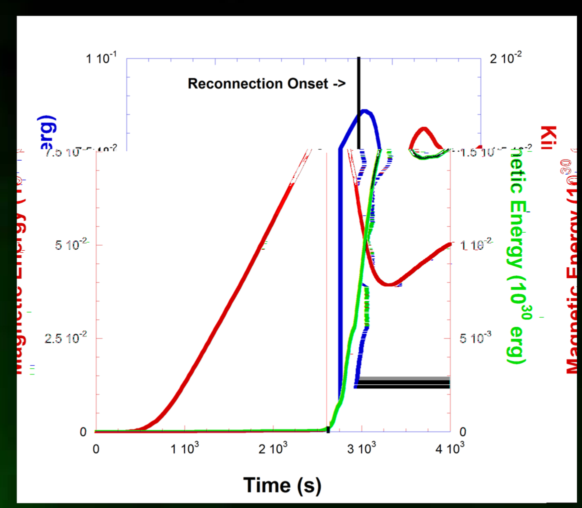
$t = 2500$ s

At $t = 2500$ s, about 1.5 turns of maximum twist have been added

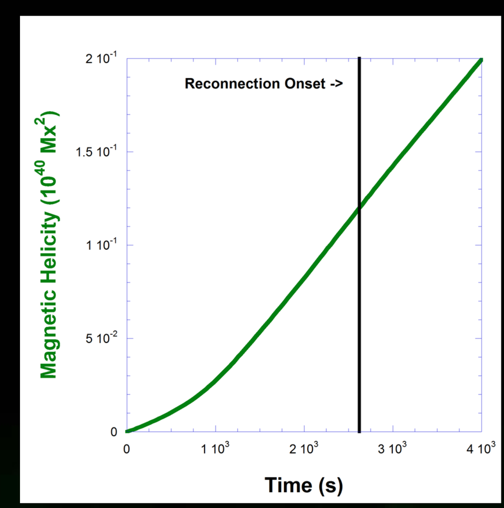
Axial symmetry-breaking is initiated by onset of ideal kink-like instability (Rachmeler et al. 2010, ApJ, 715, 1556)

Reconnection onset occurs soon after (at $t = 2625$ s), vital for rapid conversion of magnetic to kinetic energy

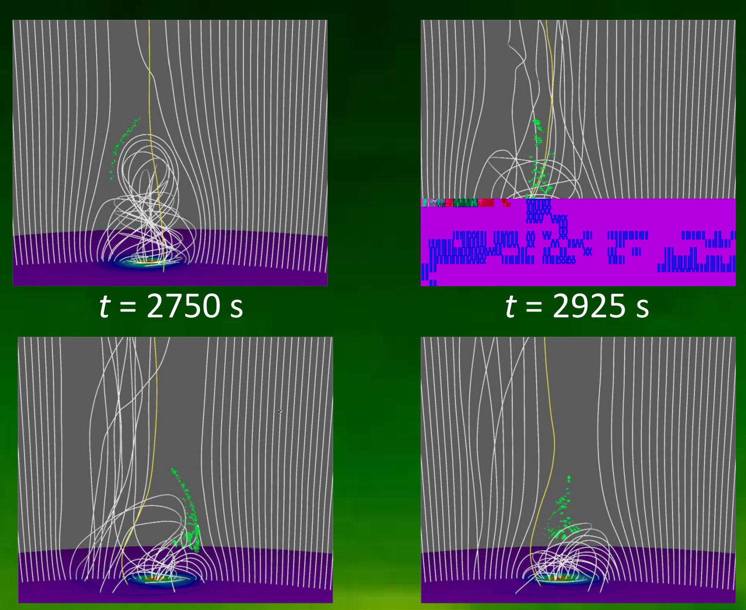
Magnetic & Kinetic Energies v. Time



Magnetic Helicity v. Time



Fast Energy Release Phase – Corona



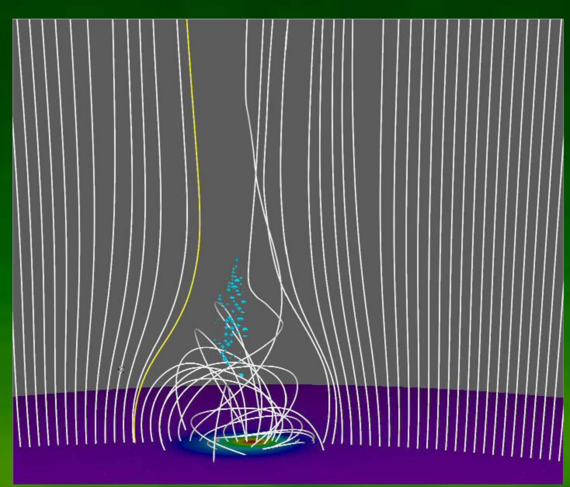
$t = 2750$ s

$t = 2925$ s

$t = 3050$ s

$t = 3200$ s

Post-Release Relaxation – Corona



$t = 4000$ s

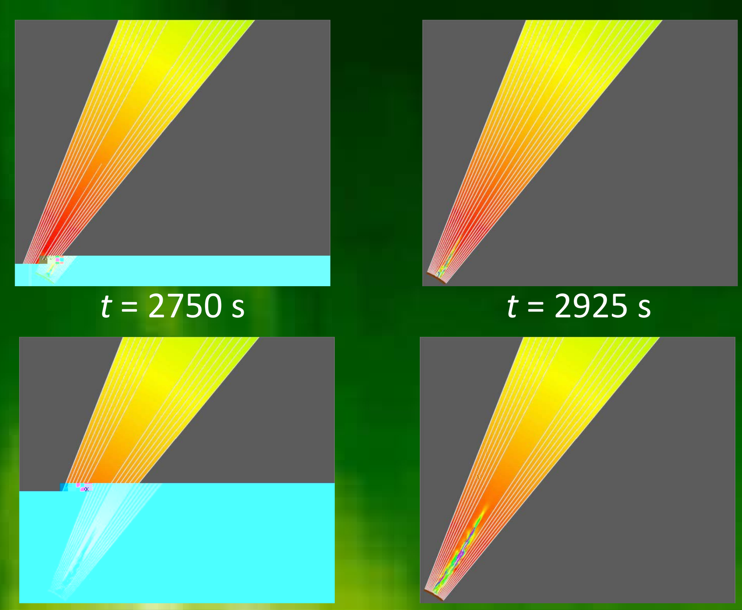
Torsional waves departed for the heliosphere as the jet spire rotated about the fan at about 75 km s^{-1}

Null point has spread into a distributed patch and fragmented (blue dots)

Strong currents outline fan surface with an arch shape

Run halted at this time due to grid size increase (×10) and jet approach to outer boundary (5 Rs)

Fast Energy Release Phase – Heliosphere



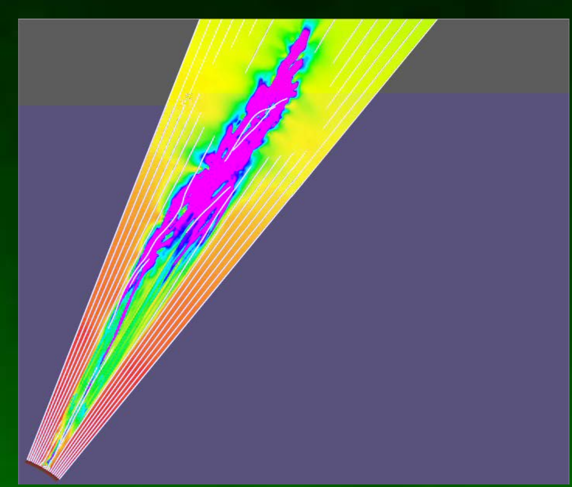
$t = 2750$ s

$t = 2925$ s

$t = 3050$ s

$t = 3200$ s

Post-Release Propagation – Heliosphere



$t = 4000$ s

Velocity magnitude color-shaded, saturated at 500 km s^{-1}

Jet front progresses at local Alfvén speed, 2000 km s^{-1}

Torsional motions of about 500 km s^{-1} accompany the jet

Twisted magnetic field lines (white) thread through and around the jet body

Summary

Solar polar jets are explosive, transient phenomena originating in coronal holes

Many jets develop vortical structures with broad bases and accelerate to highly supersonic speeds

Our numerical model replicates these properties by generating strong, torsional Alfvén waves on open magnetic field lines driven by impulsive reconnection

Jet signatures may be measurable *in situ* in the inner heliosphere by Solar Orbiter and Solar Probe Plus

Summary

In the inner heliosphere, our jet propagates at the local Alfvén speed ≈ 2000 km s^{-1}

Magnetic energy released implies an average energy flux 5×10^6 erg cm^{-2} s^{-1} ≈ background coronal/wind flux

Magnetic helicity injected implies an average helicity flux ~ 1×10^{17} Mx^2 cm^{-2} s^{-1} ≈ 100 × background flux

Spatially dispersed, temporally intermittent jets may contribute large transients to the Sun's helicity flux

Videos

Please see the author to view the accompanying videos:

Hinode's polar sea (Cirtain et al. 2007)

STEREO's polar vortex (Patsourakos et al. 2008)

ARMS jet initiation and relaxation (coronal view)

ARMS jet propagation (heliospheric view)

Acknowledgments

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